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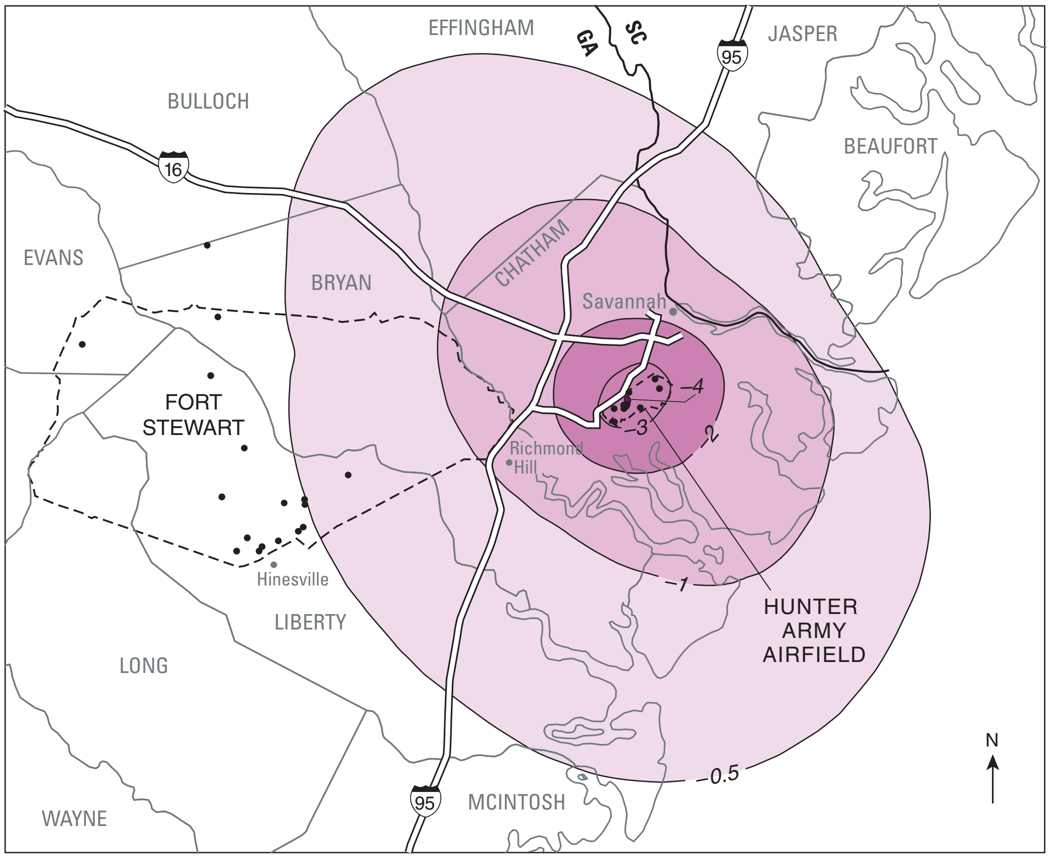
Simulation of Selected Ground-Water Pumping Scenarios at Fort Stewart and Hunter Army Airfield, Georgia



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By Gregory S. Cherry

Prepared in cooperation with the
U.S. Department of the Army, Fort Stewart

Open-File Report 2006-1148

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
Dirk Kempthorne, Secretary

U.S. Geological Survey
P. Patrick Leahy, Acting Director

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Simulation of Selected Ground-Water Pumping Scenarios at Fort Stewart and Hunter Army Airfield, Georgia

By Gregory S. Cherry

Abstract

A regional MODFLOW ground-water flow model of parts of coastal Georgia, Florida, and South Carolina was used to evaluate the effects of current and hypothetical ground-water withdrawal, and the relative effects of pumping in specific areas on ground-water flow in the Upper Floridan aquifer near Fort Stewart and Hunter Army Airfield (HAAF), coastal Georgia. Simulation results for four steady-state pumping scenarios were compared to each other and to a Base Case condition. The Base Case represents year 2000 pumping rates throughout the model area, with the exception that permitted annual average pumping rates for the year 2005 were used for 26 production wells at Fort Stewart and HAAF. The four pumping scenarios focused on pumping increases at HAAF resulting from projected future demands and additional personnel stationed at the facility and on reductions in pumping at Fort Stewart.

Scenarios A and B simulate 1- and 2-million-gallon-per-day (Mgal/d) increases, respectively, at HAAF. Simulated water-level change maps for these scenarios indicate an area of influence that extends into parts of Bryan, Bulloch, Chatham, Effingham, and Liberty Counties, Ga., and Beaufort and Jasper Counties, S.C., with maximum drawdowns from 0.5 to 4 feet (ft) for scenario A and 1 to 8 ft for Scenario B.

For scenarios C and D, increases in pumping at HAAF were offset by decreases in pumping at Fort Stewart. Scenario C represents a 1-Mgal/d increase at HAAF and a 1-Mgal/d decrease at Fort Stewart; simulated water-level changes range from 0.4 to –4 ft. Scenario D represents a 2-Mgal/d increase at HAAF and 2-Mgal/d decrease at Fort Stewart; simulated water-level changes range from 0.04 to –8 ft. The simulated water-level changes indicate an area of influence that extends into parts of Bryan, Bulloch, Chatham, Effingham, Liberty, and McIntosh Counties, Ga., and Jasper and Beaufort Counties, S.C. In general, decreasing pumping at Fort Stewart by an equivalent amount to pumping increases at HAAF reduced the magnitude and extent of drawdown resulting from the additional pumping. None of the scenarios resulted in large changes in the configuration of the simulated potentiometric surface and related ground-water flow directions.

The scenarios simulated vary from the original model only by increasing pumpage less than 1 percent of the total calibrated model withdrawals. The changes in pumpage are located near the center of the original model area. Thus, the scenarios described in this report are considered to be reasonable with no less uncertainty than the original calibrated model.

Introduction

The U.S. Department of the Army (U.S. Army) Garrison Fort Stewart and Hunter Army Airfield (HAAF), Georgia, is responsible for organizing, directing, coordinating, and controlling garrison support and service activities, including overall management of the garrison workforce. Also, the military installations house and train active military personnel and are capable of rapid deployment of the Armed Forces anywhere in the world. Fort Stewart and HAAF encompass an area of 438 square miles (mi^2) in southeastern Georgia and are located in parts of Bryan, Chatham, Evans, Liberty, Long, and Tattnall Counties (fig. 1). The U.S. Army, Fort Stewart, has plans to expand operations at HAAF, which would require construction of new housing facilities and additional quantities of water.

Ground-water withdrawal in the Fort Stewart–HAAF area is regulated and permitted by the Georgia Environmental Protection Division (GaEPD). As part of an interim water-management strategy, GaEPD has capped permitted ground-water withdrawal from the Upper Floridan aquifer at 1997 rates in parts of the coastal area (including HAAF) during 1997–2005 to limit additional drawdown in the aquifer and to reduce the potential for further saltwater intrusion (Georgia Environmental Protection Division, 1997). To aid in ground-water permit applications to GaEPD, the U.S. Army is interested in determining the effect on ground-water levels of (1) increased pumping at HAAF and (2) redistribution of pumping capacity from Fort Stewart to HAAF. To answer these questions, the U.S. Geological Survey (USGS)—in cooperation with the U.S. Army, Fort Stewart—conducted a study using an existing regional USGS MODFLOW ground-water flow model of the coastal Georgia, Florida, and South Carolina area (Payne and others, 2005; fig. 1).

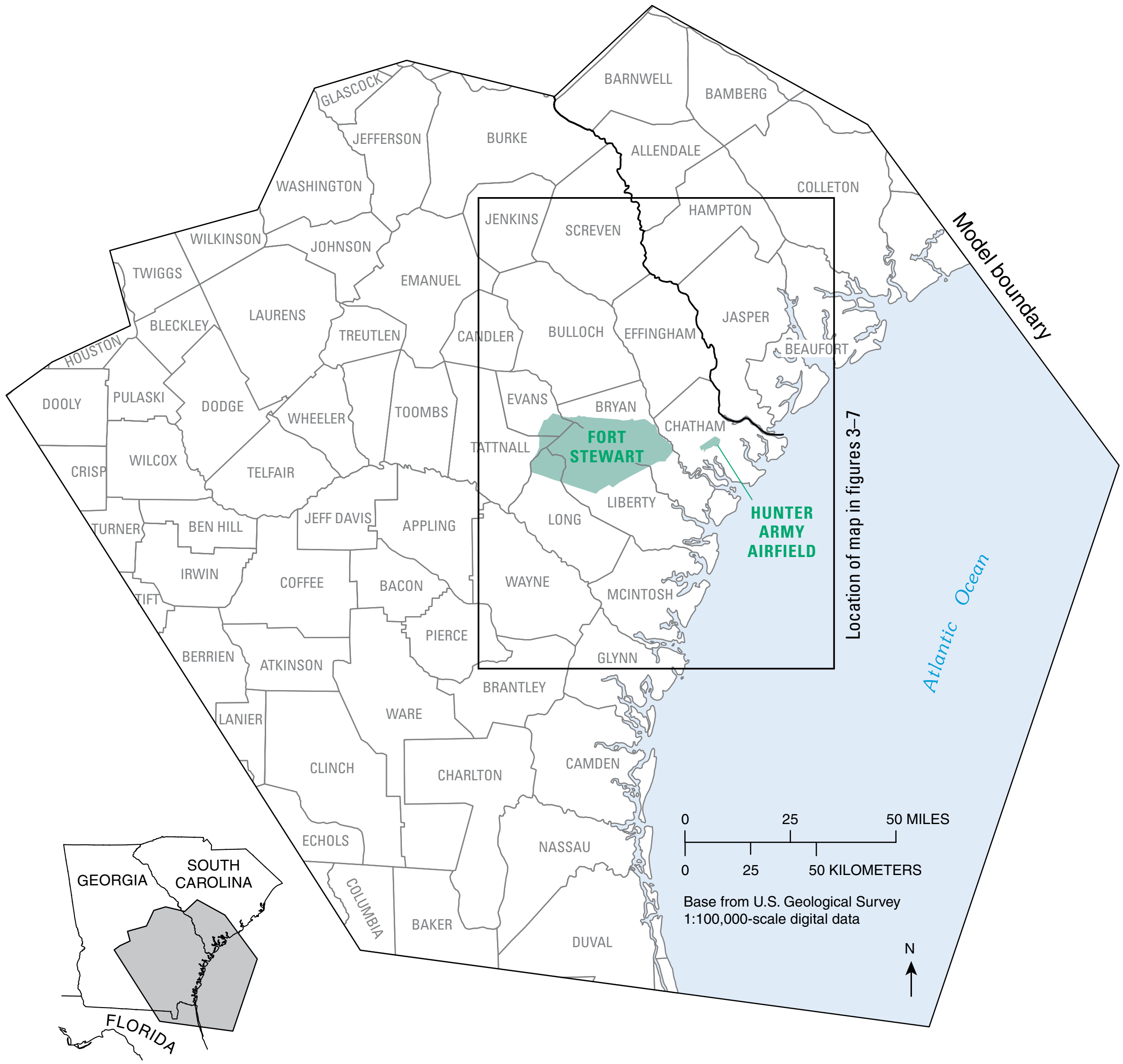


Figure 1. Location of Fort Stewart and Hunter Army Airfield, Georgia, and area of model (Payne and others, 2005) utilized in simulations.

This report describes simulated water-level changes by comparing a Base Case condition with four hypothetical steady-state pumping scenarios using the regional flow model of Payne and others (2005). The Base Case represents year 2000 pumping rates throughout the model area, with the exception that permitted annual average pumping rates for the year 2005 were used for 26 production wells at Fort Stewart and HAAF. For each scenario, the pumping distribution and simulated water-level changes relative to Base Case conditions are described. The limitations of the model analysis also are provided.

Ground-Water Flow Model

The model used in this study is described in detail in Payne and others (2005); only a brief description is included herein. Regional ground-water flow was simulated using MODFLOW-2000 (Harbaugh and others, 2000), a finite-difference, constant-density flow simulator that is widely used and is appropriate for modeling local- and regional-scale ground-water flow systems. The model boundaries encompass an area of about 42,155 mi^2 (fig. 1).

The model (Payne and others, 2005) was calibrated for 1980 and 2000 pumping conditions assuming steady-state flow. The model consists of seven aquifers and confining units. These include, in descending order:

- the confined upper and lower water-bearing zones of the surficial aquifer system, grouped together as unit 1;
- the Brunswick aquifer system confining unit (unit 2);
- the upper and lower Brunswick aquifers, grouped as the Brunswick aquifer system (unit 3);
- the Upper Floridan aquifer confining unit (unit 4);
- the Upper Floridan aquifer (unit 5);
- the Lower Floridan aquifer confining unit (unit 6); and
- the Lower Floridan aquifer (unit 7).

These units crop out to the northwest of the study area and generally dip and thicken to the southeast. The thickness, extent, and other hydraulic properties of these units, as well as the model development process are described in detail in Payne and others (2005). A schematic diagram showing model layers and boundary conditions is shown in figure 2.

The finite-difference technique used by MODFLOW requires that the simulated area be divided into discrete cells, with uniform properties throughout each cell. The MODFLOW model is horizontally discretized using a variably spaced grid, with cell sizes ranging from about 4,000 by 5,000 feet (ft) (0.7 mi^2) to 16,500 by 16,500 ft (9.8 mi^2; Payne and others, 2005). Grid density is higher at Savannah, Ga., to enable simulation of steeper head gradients near areas of concentrated pumping and to facilitate linkage with smaller-scale solute transport models being developed in those areas (fig. 3). At HAAF, mesh resolution is 5,000 by 5,200 ft, whereas at Fort Stewart the resolution is 14,900 by 16,100 ft. Each unit is represented with one layer of grid cells in the vertical dimension.

With the exception of units 5, 6, and 7 (Upper and Lower Floridan aquifers and intervening confining unit), lateral boundaries for all layers are designated as no-flow. For layers 5–7, the lateral boundaries on all sides of the model, except for the southern and southwestern sides, also are designated as no-flow. The southern and southwestern lateral boundaries are set as specified head for the layers representing the Upper Floridan aquifer (unit 5), the Lower Floridan aquifer (unit 7), and the intervening confining unit (unit 6). For these three units, the value assigned to specified-head cells is based on Upper Floridan aquifer head estimated from potentiometric-surface maps.

The bottom boundary of the model is no-flow, whereas the top boundary is set as a head-dependent flux (or general head) boundary condition, with a controlling specified head and a conductance term that regulates the flux into the top layer of the model. The controlling head is the water-table altitude in the onshore area, and the freshwater equivalent of the saltwater head in the offshore area. In the onshore area, the conductance is set to limit the amount of recharge entering the system in any given grid cell to less-than-maximum estimated recharge from baseflow estimates (Priest, 2004). For the purpose of simplification and because little is known about hydraulic properties in the offshore area, the conductance imposed in the offshore area is large, posing minimal resistance to flow in or out of the system.

Pumping distribution was assigned based on county-aggregate and site-specific data, which were used to estimate average annual pumpage for 1980, 1997, and 2000. Pumpage is assigned to units 3 (Brunswick aquifer system), 5 (Upper Floridan aquifer), and 7 (Lower Floridan aquifer). The sum of site-specific and nonsite-specific pumping rates for 1980 and 2000 were assigned to the model grid cell in which their respective assigned locations and aquifers were situated. This report focuses on the pumping distribution during 2000, with modifications made to pumping rates at Fort Stewart and HAAF within the Upper Floridan aquifer. The total estimated pumping in the model area during 2000 was about 810 Mgal/d. According to water-use estimates (Fanning, 2003), pumping from the Upper Floridan aquifer near Fort Stewart and HAAF was 0.7 Mgal/d in Evans, 0.7 Mgal/d in Long, 1.6 Mgal/d in Bryan, 15.7 Mgal/d in Liberty, and 68.2 Mgal/d in Chatham Counties, Ga. The single largest concentration of pumping in Georgia was at Jesup, Wayne County, at a rate of about 60 Mgal/d from the Upper Floridan aquifer during 2000 (Fanning, 2003).

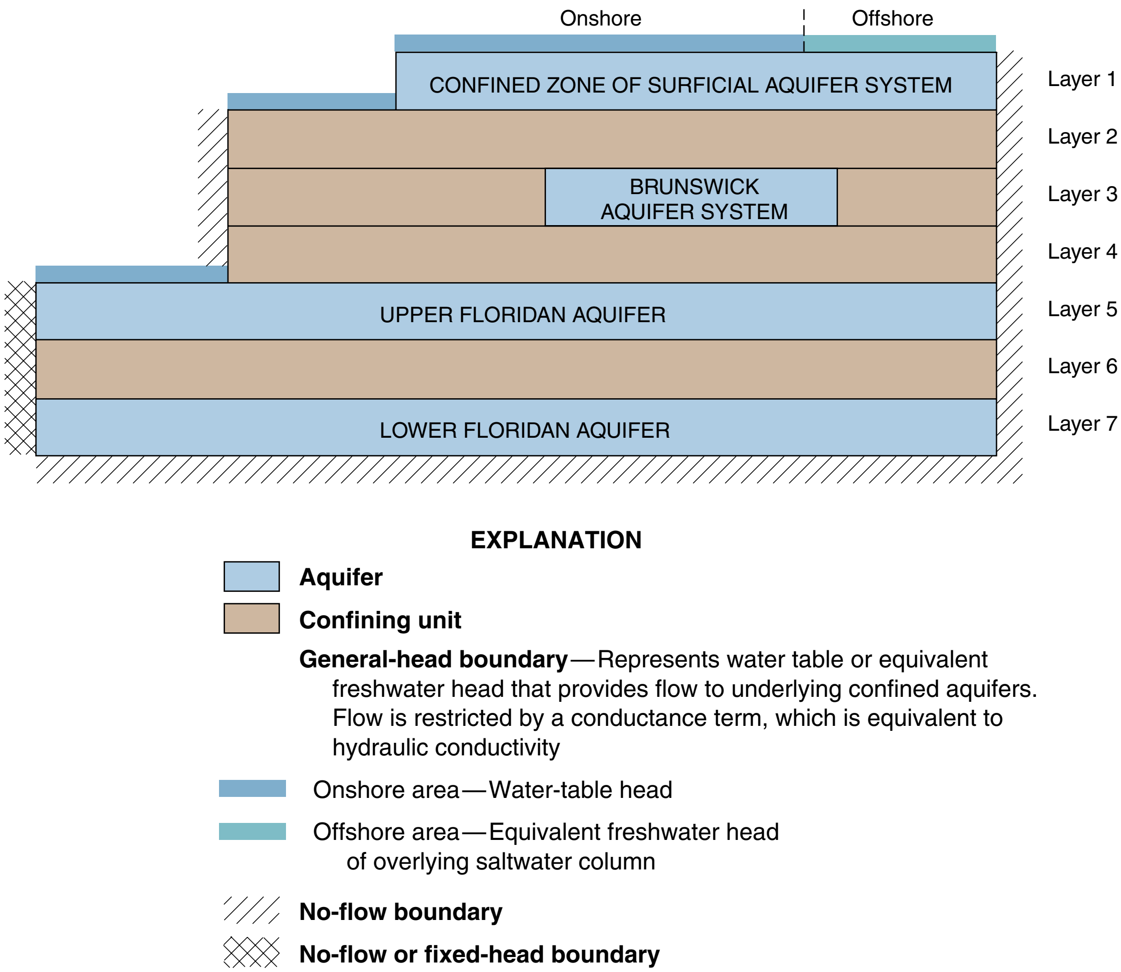


Figure 2. Schematic diagram showing model layers and boundary conditions (from Payne and others, 2005).

Simulation of Ground-Water Pumping Scenarios

The calibrated MODFLOW model (Payne and others, 2005) was used to simulate the Base Case condition or scenario and to provide insight into the potential effects of four different pumping scenarios on water-levels in the Upper Floridan aquifer. The scenarios were designed to simulate (1) the effect of incremental pumping increases at HAAF (Scenarios A and B); and (2) the relative effects of transferring pumping from Fort Stewart to HAAF (Scenarios C and D). All pumping was from the Upper Floridan aquifer.

The Base Case steady-state scenario represents year 2000 pumping rates throughout the model area, with the exception that permitted annual average pumping rates for the year 2005 were used for 26 production wells at Fort Stewart and HAAF. Table 1 includes information about well depth, pump capacity, and pumping rate used in the Base Case simulation; figure 3 shows the spatial distribution of production wells and the variation in grid-cell size from the finer mesh near the City of Savannah to the coarser mesh on Fort Stewart. Note that in some cases, the Base Case pumping rate assigned to an individual well may be *higher* than the rated pump capacity; this results from distributing the total *permitted* capacity among the several wells, which in some cases exceeds the rated capacity of an individual well.

The Base Case simulates permitted pumping rates of 4.5 Mgal/d at Fort Stewart and 1.03 Mgal/d at HAAF, which is substantially higher than the actual pumping rates for 2005 of 2.3 and 0.8 Mgal/d, respectively. Simulated pumping at Fort Stewart was evenly distributed to the several wells (0.3 Mgal/d) with the exception of wells FS11, FS12, and FS13, which were held within a range of 0.11 to 0.12 Mgal/d owing to their lower pumping capacity (table 1). The simulated pumping distribution among the nine wells on HAAF was relatively even ranging from 0.1 to 0.12 Mgal/d.

The Base Case was used as a basis for comparison of simulated heads from each of the four pumping scenarios. The simulated Base Case potentiometric-surface map of the Upper Floridan aquifer (fig. 4) indicates HAAF is within the regional cone of depression created by ground-water pump-

age in the Chatham County area. The principal direction of ground-water flow in the study area is toward the cone of depression. The simulated water-level changes, presented for each scenario, represent additional drawdown within the area influenced by the regional cone of depression (fig. 4). None of the scenarios resulted in large changes in the configuration of the simulated potentiometric surface and related ground-water flow directions.

Scenario A represents a 1-Mgal/d increase in pumping rate at HAAF that was distributed evenly among the nine productions wells located at HAAF (table 2, fig. 5). The simulated water-level changes indicate an area of influence that extends into parts of Effingham, Bulloch, Bryan, Liberty, and Chatham Counties, Ga., and Jasper and Beaufort Counties, S.C. In Chatham County, the water-level changes range from approximately –1.4 to –4.1 ft and the –3-ft line of equal simulated water-level change approximates the boundaries at HAAF (table 2 and fig. 5).

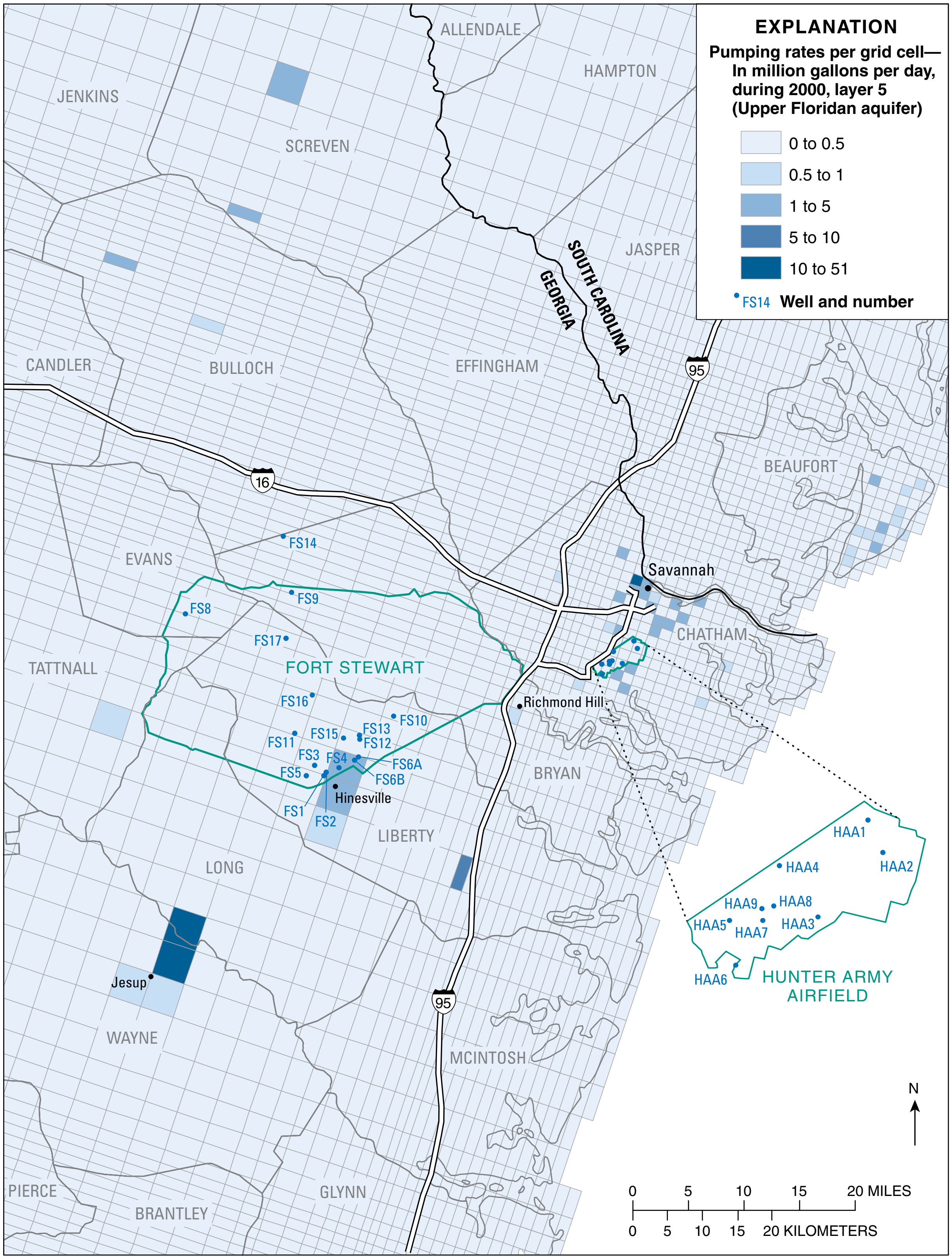
Scenario B represents a 2-Mgal/d increase in pumping rate at HAAF that was distributed evenly among the nine production wells located at HAAF (table 2, fig. 6). The simulated water-level changes are wider in aerial extent than in Scenario A, with approximately double the drawdown. For example, the –0.5-ft line of equal simulated water-level change in Scenario A (fig. 4) has been replaced by the –1-ft line in Scenario B (fig. 6). In Chatham County, the water-level changes range from approximately –2.9 to –8.2 ft and the –6-ft line of equal simulated water-level change approximates the boundaries at HAAF.

Scenario C represents a 1-Mgal/d increase of pumping at HAAF and a decrease of 1 Mgal/d at Fort Stewart (table 2, fig. 7). The 1-Mgal/d increase was distributed evenly among the nine production wells located at HAAF and the 1-Mgal/d decrease was subtracted evenly among the 17 production wells located at Fort Stewart. The maximum drawdown in Chatham County for Scenario C ranged from 1.1 to 3.8 ft. Reducing pumping at Fort Stewart resulted in a water-level recovery exceeding 0.2 ft across the base (maximum 0.4 ft), and helped reduce the area influenced by increased pumping at HAAF. For example, the area in which simulated declines exceeded 0.5 ft decreased appreciably when compared with Scenario A (fig. 5), which involved a 1-Mgal/d pumping increase at HAAF without an accompanying reduction at Fort Stewart. Although the 1-Mgal/d reduction resulted in some recovery at Fort Stewart, the recovery is lower in magnitude than the amount of drawdown resulting from the same amount of pumping at HAAF (Scenario A, fig. 3). The smaller recovery could be attributed to wider spacing of pumping wells at Fort Stewart, to a coarser model grid size, or to the relatively higher hydraulic conductivity of the Upper Floridan aquifer near the base.

Table 1. Selected well data for production wells and 2005 permitted pumping rates (Base Case) at Fort Stewart and Hunter Army Airfield, Georgia.

[ft, foot; gal/min, gallon per minute; Mgal/d, million gallons per day; —, no data. In some cases, the Base Case pumping rate assigned to an individual well may be higher than the rated pump capacity; this results from distributing the total permitted capacity among the wells, which in some cases exceeds the rated capacity of an individual well]

Well number (see fig. 3)	Well depth below land surface (ft)	Pump capacity (gal/min)	Base Case assigned pumping rate (Mgal/day)
	Fort Stewart		
FS1	816	2,100	0.3
FS2	808	1,400	0.3
FS3	750	1,400	0.3
FS4	802	1,600	0.3
FS5	779	1,100	0.3
FS6	472	500	0.3
FS7	508	500	0.3
FS8	706	400	0.3
FS9	560	175	0.3
FS10	600	190	0.3
FS11	500	75	0.1
FS12	605	80	0.1
FS13	605	80	0.1
FS14	705	535	0.3
FS15	—	—	0.3
FS16	—	—	0.3
FS17	—	300	0.3
		Total	**4.5**
	Hunter Army Airfield		
HAA1	504	1,300	0.1
HAA2	555	1,300	0.1
HAA3	370	30	0.1
HAA4	360	80	0.1
HAA5	380	30	0.1
HAA6	450	70	0.1
HAA7	375	80	0.1
HAA8	623	1,000	0.1
HAA9	—	180	0.1
		Total	**1.0**



Base from U.S. Geological Survey 1:100,000-scale digital data

Figure 3. Well locations and model grid orientation in the vicinity of Fort Stewart and Hunter Army Airfield, Georgia (see table 1); and simulated ground-water pumpage for the Upper Floridan aquifer, 2000 (from Payne and others, 2005).

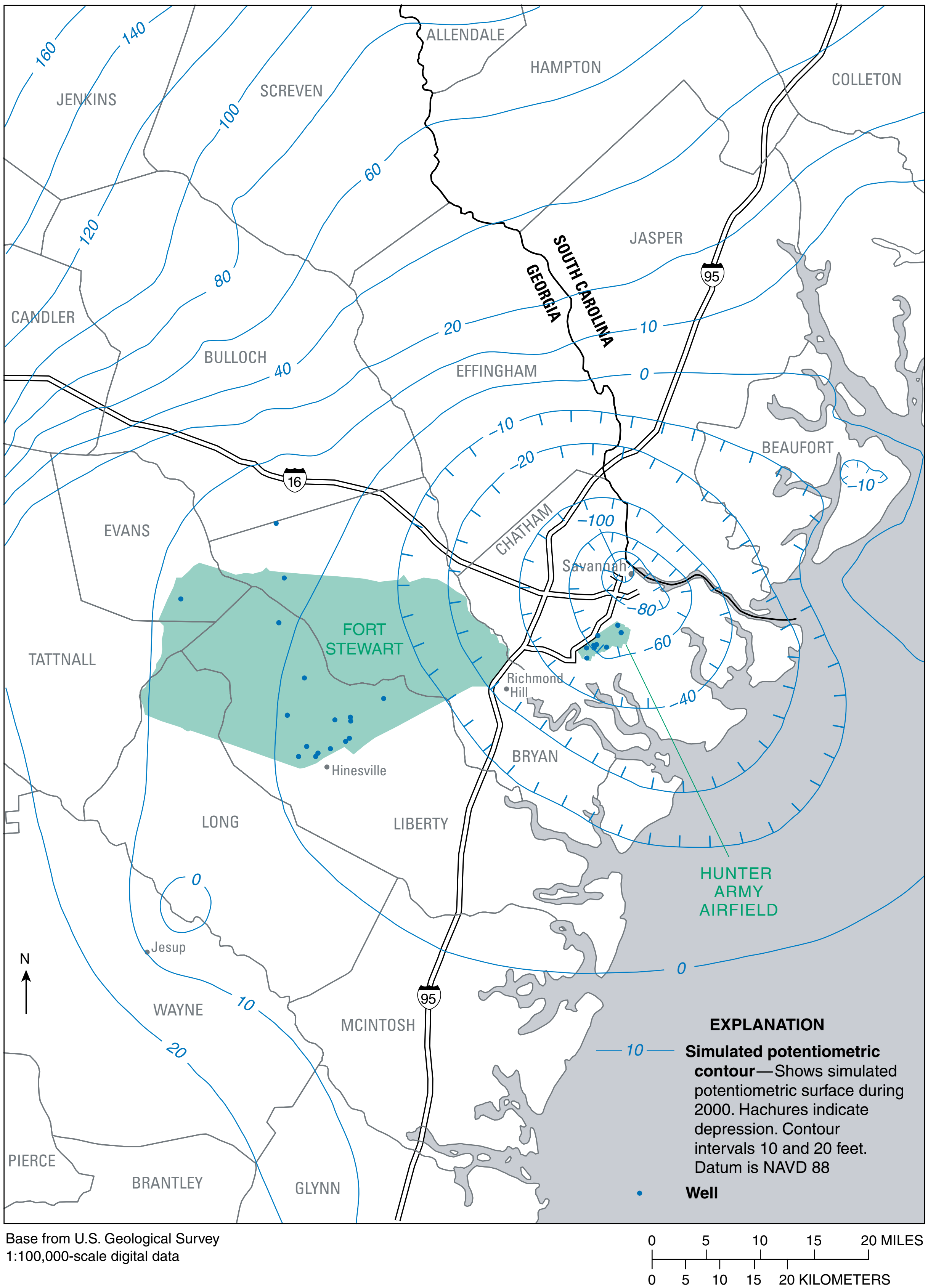


Figure 4. Simulated potentiometric surface of the Upper Floridan aquifer during 2000 using Base Case pumping rates for Fort Stewart and Hunter Army Airfield, Georgia (see table 2).

Table 2. Simulated pumpage at Fort Stewart and Hunter Army Airfield, Georgia, and maximum water-level changes in layer 5 of the ground-water flow model (Upper Floridan aquifer).

[Mgal/d, million gallons per day; –, water-level decline]

Designated area	[1]2000 pumpage (Mgal/d)	Base Case 2005 permitted pumpage (Mgal/d)	Scenario A		Scenario B		Scenario C		Scenario D	
			Pumpage (Mgal/d)	Maximum water-level change (feet)	Pumpage (Mgal/d)	Maximum water-level change (feet)	Pumpage (Mgal/d)	Maximum water-level change (feet)	Pumpage (Mgal/d)	Maximum water-level change (feet)
Fort Stewart	2.3	4.5	4.5	–1.4	4.5	–2.9	3.5	–1.1 to 0.4	2.5	–2.2 to 0.04
Hunter Army Airfield	0.3	1.0	2.0	–4.1	3.0	–8.2	2.0	–3.8	3.0	–8.1
Total	**2.6**	**5.5**	**6.5**		**7.5**		**5.5**		**5.5**	

[1]Payne and others (2005).

Scenario D represents a 2-Mgal/d increase in pumping at HAAF and a decrease of 2-Mgal/d at Fort Stewart (table 2, fig. 8). The 2-Mgal/d increase was distributed evenly among the nine productions wells located at HAAF and the 2-Mgal/d decrease was subtracted evenly among the 17 production wells located at Fort Stewart. The maximum drawdown in Chatham County for Scenario D ranged from 2.2 to 8.1 ft. As was the case for Scenario C, reducing pumping at Fort Stewart by an amount equivalent to pumping increases at HAAF, reduced the extent of water-level decline resulting from the HAAF increase. For example, the area in which simulated declines exceeded 0.5 ft decreased appreciably when compared with Scenario B (fig. 6), which involved a 2-Mgal/d pumping increase at HAAF without an accompanying reduction at Fort Stewart. Although the 2-Mgal/d reduction at Fort Stewart reduced the extent of drawdown resulting from the HAAF increase, the reduction resulted in less recovery at Fort Stewart than in Scenario C, which involved one-half the pumping rate. This smaller water-level recovery is likely because the zone of influence from pumping at HAAF for Scenario D extends beneath Fort Stewart, whereas the zone of influence for Scenario C is reduced in extent or is a lower magnitude.

Model Limitations

The four steady-state scenarios presented in this report are believed to reasonably depict changes in ground-water levels resulting from pumping changes ranging from 1 to 2 Mgal/d at Fort Stewart and HAAF, but results are limited by model assumptions and design. Model results must be interpreted in light of uncertainties and approximations inherent in the formulation of the model.

This ground-water flow model used in this study is subject to the limitations described by Payne and others (2005). These limitations include error and uncertainty in field measurements of water level and in estimates of pumping; limitations of the conceptual models; approximations made in representing the physical properties of the flow system and errors inherent in estimating the spatial distribution of these properties; approximations made in the formulation and application of model boundary and initial conditions; errors associated with numerical approximation and solution of the mathematical model of the flow system; and assumptions made in using the models to predict the future behavior of the flow system.

Simulated water-level changes may be influenced by the difference in mesh resolution at the two sites. The larger mesh size at Fort Stewart will result in a more generalized water-level response that is averaged across the larger cell area. Water-level changes at HAAF will have higher resolution because of the finer mesh. It is possible that the model was more responsive to pumping near HAAF as a result of the finer grid-cell size, which was intended to simulate the steep cone of depression located near Savannah, Ga. The increase in pumpage for these four scenarios is less than 1 percent of the total withdrawals for the 2000 calibrated model (Payne and others, 2005). Additionally, the location of the pumpage is near the center of the calibrated model.

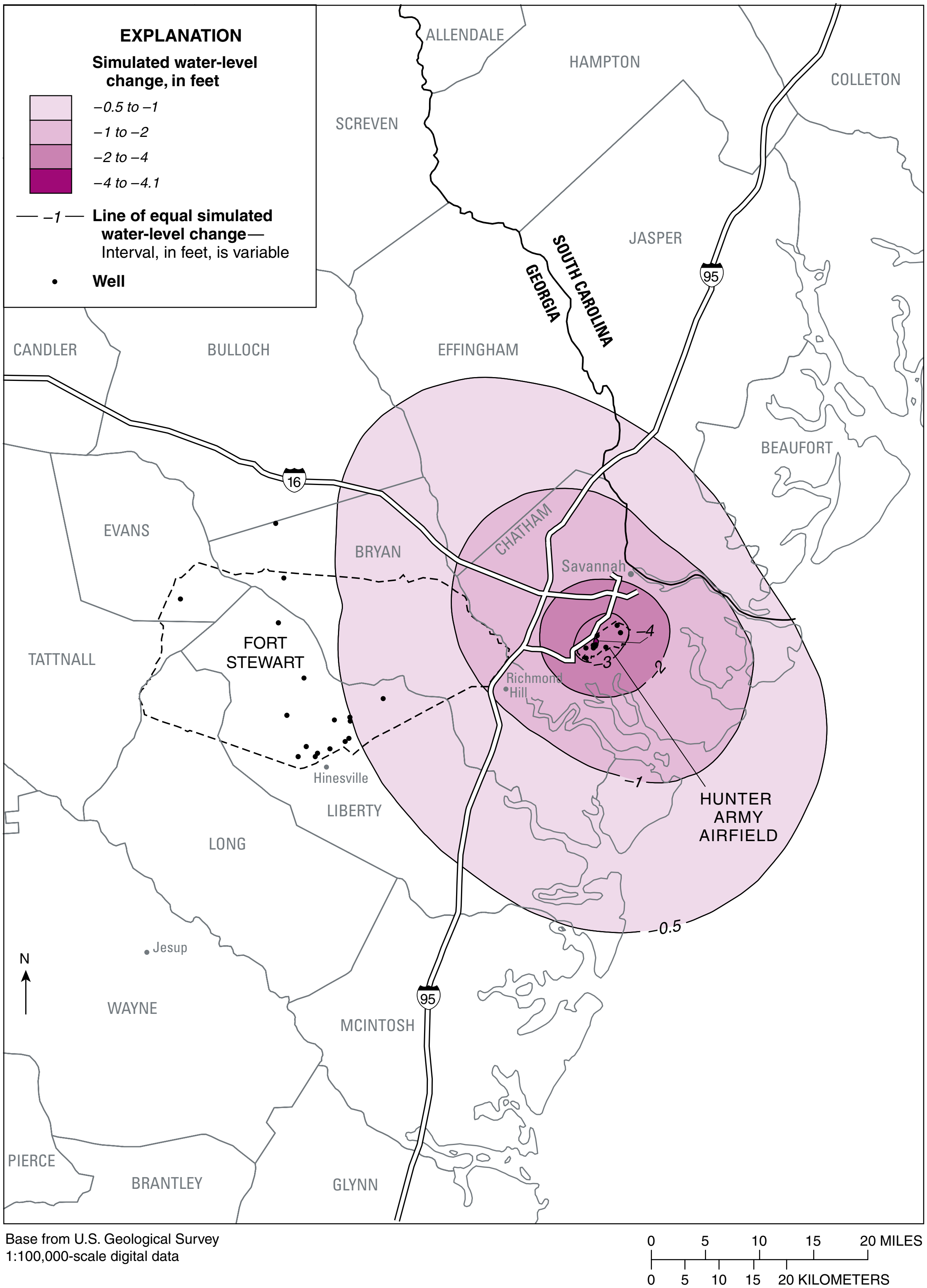


Figure 5. Simulated water-level change between Base Case conditions (2005 permitted pumping for Fort Stewart and Hunter Army Airfield, Georgia) and Scenario A (increase pumping by 1 million gallons per day at Hunter Army Airfield).

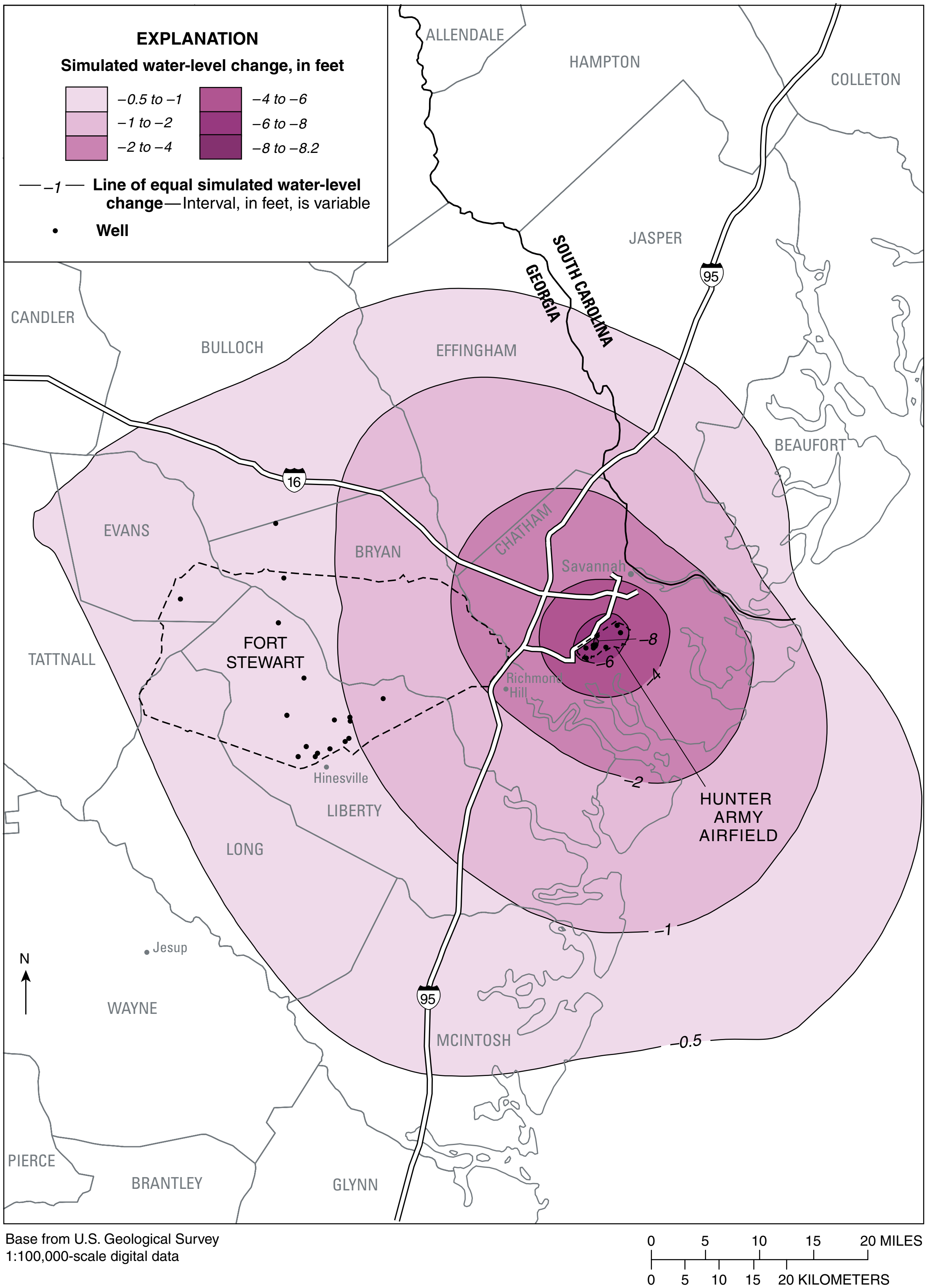


Figure 6. Simulated water-level change between Base Case conditions (2005 permitted pumping for Fort Stewart and Hunter Army Airfield, Georgia) and Scenario B (increase pumping by 2 million gallons per day at Hunter Army Airfield).

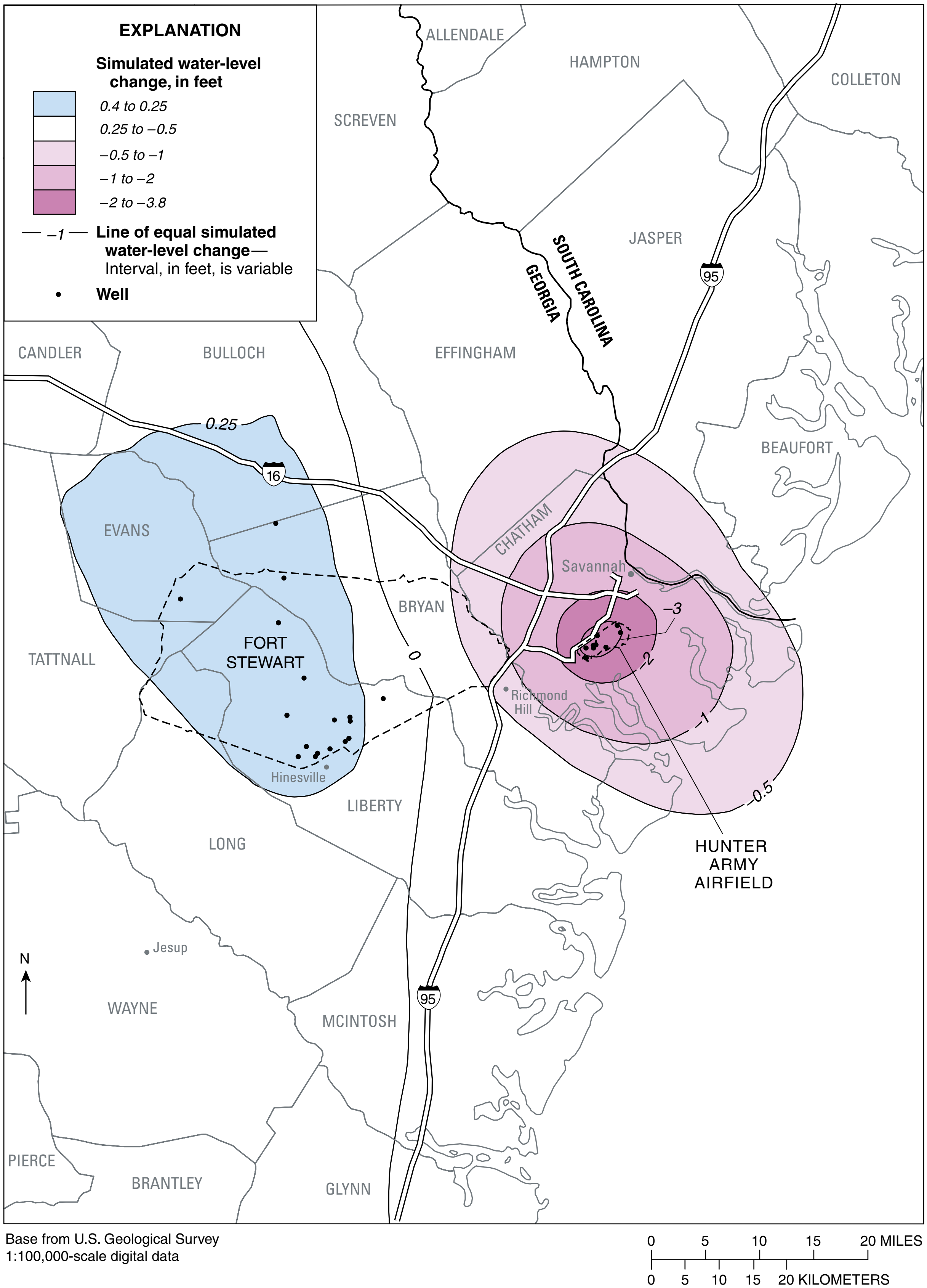
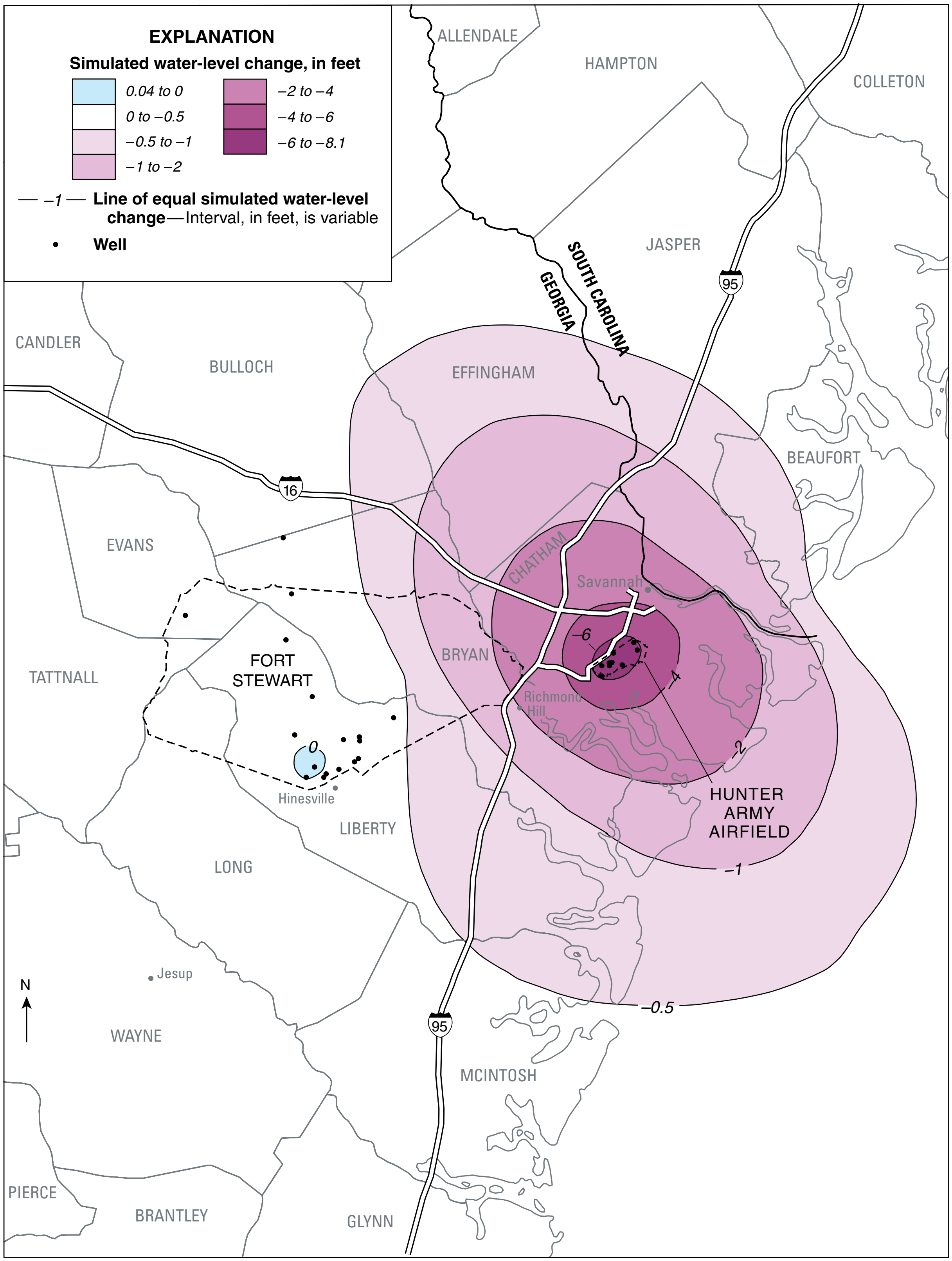


Figure 7. Simulated water-level change between Base Case conditions (2005 permitted pumping for Fort Stewart and Hunter Army Airfield, Georgia) and Scenario C (decrease pumping by 1 million gallons per day at Fort Stewart and increase pumping by 1 million gallons per day at Hunter Army Airfield).



Base from U.S. Geological Survey
1:100,000-scale digital data

0 5 10 15 20 MILES
0 5 10 15 20 KILOMETERS

Figure 8. Simulated water-level change between Base Case conditions (2005 permitted pumping for Fort Stewart and Hunter Army Airfield, Georgia) and Scenario D (decrease pumping by 2 million gallons per day at Fort Stewart and increase pumping by 2 million gallons per day at Hunter Army Airfield).

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